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Designing to Remove Phosphorus by Using Metal Salts and Polymers in Conventional Plants

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16. Abstracts

The report discusses the use of metal salts and polymers in otherwise conventional plants. (Tertiary systems are not covered.) These are: Metal salts: FeCl3, pickle liquor, alum, and sodium aluminate (which also provides alkalinity)...liquids are best (cost, effectiveness, flexibility, ease of handling); Polymers: most come dry; no universal choice; 3 categories.

17. Key Words and Document Analysis. 17a. Descriptors

*Sewage treatment
*Phosphorus,
*Chemical removal(sewage treatment),
Metals,
Iron chlorides,
Polymers,
Alums,
Sodium,
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Flocculating,
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Clarification,
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"DESIGNING TO REMOVE PHOSPHORUS BY USING METAL SALTS AND PLOYMERS IN CONVENTIONAL PLANTS"

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"DESIGNING TO REMOVE PHOSPHORUS BY USING
METAL SALTS AND POLYMERS IN CONVENTIONAL PLANTS"

James E. Laughlin, P. E.

1. Why are we here today?
   a. To discuss use of metal salts and polymers in otherwise conventional plants. Tertiary systems are not covered.
   b. Recent reports (1) (2) (3) (4) (5) show progress has occurred.
   c. Designers can – and must – proceed with positive pragmatism.
   d. Material here is based on fundamentals proven in plant scale operations.
   e. Operational aspects are included, and deserve design emphasis.
   f. Designers must be part of startup and initial operations.
   g. Cost information is skimpy. It's easy to figure for each situation.
2. Should you use these processes? When and Where?
   a. Ignoring "the great P debate", (6) is this trip necessary? Local quality standards (including BOD and suspended solids) yield the answer.
   b. Modification of existing plants usually simple, and inclusion in new plants is minor. Capital costs are quite low.
   c. Degree of treatment dilemma: going from 80% to 95% phosphorus removal may increase operation costs 50% or more, but physical facilities are identical and operational flexibility allows choice at later time.

d. Role of the Owner: alpha and omega. Reduction in solids and BOD may be pivotal. Success demands commitment to:

...intelligent 24-hr operation (does not mean 3 men)

...lab support beyond conventional plant operations

...5¢/1000 gal (chemicals are most of this).

3. Process variations: several possibilities lead to one clear choice

a. Primary clarifier... greatest sludge yield of any variation, but substantial reduction of subsequent biological sludge

... escaping colloids are reduced in following units

... lowest ortho-P fraction

... greatest chemical demand of any location

... 50% BOD reduction appeals in overloaded plant.

b. Biological unit ... filter may blotch and slough, won't plug; however, not an effective point of application; nothing to gain

... contact stabilization modification proposed (7)

... MLSS provide great sorptive area

... aeration tanks afford mixing and detention; can add at middle or end, but enroute to final clarifier is mot popular

... effect of metals on MLSS biota still unclear (8) but apparently not detrimental

... large MLSS floc may form and this could reduce exposure of active biota and impede transfer of oxygen, offgases, and substrate

... nitrification may be suppressed by pH shock.

c. Final clarifier ... one shot last chance situation, but quite effective

... stearic hindrance of detergents reduced here

... ortho-P predominates, and is desired form

... underflow stimulates primary settling if returned there in trickling filter plant

... activated sludge unit has far more solids handling capacity, but has more load too.

d. Multi-point facilities: inexpensive approach to effective performance

... allows total feed to any of several points

... permits split feed, a popular approach at several plants.

4. Trial efforts: How big and how long? A bold approach is justified.

a. Jar test (9) ... a vital but treacherous ally

... auxiliary flash mix highly desirable

... hydraulic similitude by eyeball (stare and compare)

... assume plus flow in setting agitation times

... dynamic "settling" is a must

... practice, practice, practice.

b. Other lab tests work (10) (11) but dawn comes slowly at "the sewer plant".

c. Pilot facilities: an exercise in futility due to cost, operational vagaries, and the perfidious scale factor.

d. Full plant (or isolated module) trial: going in style, with confidence without going broke. Fig. 1: typical 1.6 MGD plant in Richardson, Texas (12).

5. Chemicals: who are they, what do they do, and how?

a. Available forms (13)

Metal salts: $FeCl_3$, pickle liquor, alum, and sodium aluminate (which also provides alkalinity)...liquids are best (cost, effectiveness, flexibility, ease of handling)

Polymers: most come dry; no universal choice; 3 categories

b. Technical Details on Coagulants

...alum (48.5% soln of filter alum is 8.25% Al_2O_3) weighs 11.1 lb/gal, and 4.37% of that is Al

...aluminate (46% soln) is 15.1% Al by weight

...ferric chloride varies from 35% to 45% soln, according to weather (agitated 45% soln freezes at 45° F, and 37% soln at 15° F); 40% soln weighs 11.9 lb/gal, and 16.4% of that is Fe

...see tech bulletins for complete details on all coagulants and polymers.

c. Functions: precipitate P and removal all colloids within range

... Pptn of ortho-P to insoluble colloid is solely by metal salts

... coagulation (destabilization) of all colloids by metals and polys

... flocculation of destabilized colloids by metals and polys

d. Precipitation: reactions and kinetics (14)

... produces metal phosphates, of some sort (15)(16)

... fast, near complete in one second

... pH will be depressed; 6.5 good value, but watch alkalinity

... coagulation competes for metal species

... polyelectrolytes not involved, defer their addition.

e. Coagulation: reactions and kinetics (17)

... metal coagulation very rapid: one second

... metal radicals are complicated, probably polymerize (18)

... polymer coagulation less rapid: seconds to minutes

... homegrown polymers have obscure role (19) (20)

... key developments in coagulation: reduction of surface charge on hydrophobes, dehydration of water layer on hydrophyls.

f. Flocculation: reactions and kinetics

... flocculation proceeds languidly thru decreasing energy levels over a period of minutes; involves both metals and polys

... key developments in flocculation: glue colloids together at moment of collision, provide skeleton for dense floc, act as broomstraws for sweeping up surviving colloids.

g. Physical arrangements inferred:

... flash mix intensely for 1-30 seconds (adding metal salt)

... high energy flocculation 1-5 minutes (add polys near midpoint)

... low energy flocculation 5-20 minutes

... facility requirements are modest, largely inherent in conventional plant.

6. Hardware: type, size, location and use (21)

a. Universal applicability: a happy new twist

b. Flash mixing: our most grevious shortcoming (22) (23)

... raw inflow requires hydraulic jump, drop box, drop manhold, air agitation, or pump intake; all relatively unsatisfactory due to low energy levels

... treated flow allows use of propeller or turbine mixer, vortex unit, jet, or other devices (24) (25) (26). Inline approach is excellent. Baffled basin is poor choice

... Gt has little value; G is suspect but use it with care, supplying an input of 800-1000 for up to 30 seconds. Be prepared to adjust hardware.

... For electrically driven mechanical mixer, calculate:

$G = [\ (WHP)\ (550) / (\mu)\ (V)\ ]^{0.5}$, where

(WHP) is delivered water horsepower or

(KVA) (Mtr Eff) (Pwr Factor)/(0.746)

(μ) is absolute viscosity, 0.2×10^{-4} at 70° F

(V) is mixed volume in cubic feet

... Analyzing a baffled basin (or other head loss unit) for G:

$G = [\ (62.4)\ (H) / (T)\ (\mu)\ ]^{0.5}$, where

H = head loss thru basin; one foot for example

T = detention time; 31.2 seconds for example

μ = absolute viscosity; 0.2×10^{-4} for example

$= [\ (62.4)\ (1.0) / (31.2)\ (0.2 \times 10^{-4})\ ]^{0.5}$

$= 316\ sec^{-1}$

and (1) G value of 316 less than 800-1000 recommended

(2) Introduction of energy over a 31-second period is inefficient when chemical reactions are complete in 5% of that time

(3) In a drop box detaining flow for 3.12 seconds, G becomes 1000. Required volume of 4.5 Cu Ft/MGD presents design challenge.

... in an open flash mix box, mix at front end and leave at least threefold following volume for future needs (e.g. controlled high energy flocculation); Fig 2: junction box can be modified to serve

... proper mix in aeration basin is problematical; just put chemical in and see how it works.

c. Flocculation: special mechanisms and tankage not needed; use water plant technology for analysis (27) (28) (29)

... high energy flocculation occurs in effluent end of mix unit, pipe, and clarifier centerwell (or equivalent); energy level is declining; clarifier inlet hydraulics are critical

... low energy flocculation occurs in blanket near clarifier inlet

... baffles, paddles, etc. may be added later; probably not needed

... can flocculate in activated sludge aeration tank.

d. Chemical injection: two chemicals and two exhortations

... Coagulant: inject full strength (to prevent premature hydrolysis) into intense dispersion zone, with one inlet pipe per mixing unit up to 8-10 MGD; current unpublished work may open trend to controlled predilution to enhance flash mix operation (30)

... Polymer: have several inlet points available, injecting a diluted stream (multi-port or header device above 3 MGD). Aim for thorough dispersion at moderate energy levels.

e. Feeding equipment

... many types of variable discharge positive displacement pumps can serve: diaphram, plunger, gear, progressing cavity

... proper selection of pump materials allows interchange between coagulant and polymer service

... use pumps designed for 500 psi service, put in a 40 psi backpressure valve and neglect head loss in piping that follows

... backpressure seats check valves to improve accuracy; double check valves are good

... don't select too large a pump: low-range control difficult; some pumps have interchangeable heads of different sizes

... ratio control helpful, in addition to percent output control

... no problems in calibration and recalibration; pump water first

... pumpage record usually based on operator's log

... Fig 3: another approach: gravity flow; use mag meter, T-I-R and air or electric throttling valve

... Fig 4: any system should include or adapt to auto control; can go as far as compound loop system--if reliable P-analyzer is included; figure shows "feed forward" system where effluent monitoring can be used to trim base dose.

f. Piping

... PVC or FRP, protected from freezing as required

... provide flushing tees following pumps

... accumulators not necessary; manual air blowoffs recommended, and make good sampling-calibrating ports

... put strainers on pump suctions, and make lines big

... dilute poly pump discharge with about 20 gpm water, followed by at least 50-ft run of pipe; use jet or turbulence section if pipe run is too short

... include hose stations for washdown of spillage.

g. Storage tanks

... fiberglass (filament wound or layup) from good supplier

... natural amber or colored tanks are attractive

... coagulant: size for 7-10 day supply on 2/1 mole ratio; approx 3000 gal/MGD for alum (equals 3 weeks for $FeCl_3$ or aluminate); 6000 gal tank will accept 5000 gal tank truck lots

... tank hardware: sight gauge, manhole, fill inlet with snap coupling, pump suction, vent, flush-bottom drain

... use polyurethane pad between slab and tank, unless weather dictates heated pad to keep coagulant warm

... polymer: size for 2-3 day supply of 0.5% soln; this is 400 gal/MGD at 2 mg/l dose. Can always dilute below 0.5% and will probably want to

... same tank fittings as coagulant, plus over-powered mixer for 1000 cp viscosity; fill inlet connects to water; disperser funnel also requires water

... consider shelter for polymer units; operators appreciate this

... auto poly dispersers available and have been successfully used at a dozen plants; check with equipment vendors (31) (32).

7. Dosage selection and control: key to success

a. Coagulant: here is where the money and performance are

... key parameters: mole ratio fed, and effluent P

... Fig 5: assess P income both on hourly and daily composite basis; if serving urban or suburban areas, expect high P income on Saturday, low on Sunday, typical on weekdays

... convert lb/day to lb-mole/day; set mole ratio at 2.1 or 1.5/1; factors are 31 for P, 27 for Al, and 56 for Fe; typical calculation would be:

If Phosphorous Income (As P) is 310 Lb/Day:

310/31 = 10 Lb-Moles/Day

If Desired Mole Ratio (M/P) is 2/1:

(2/1) (10) = 20 Lb-Moles Metal Required

Using Liquid Alum:

(20/1) (27) = 540 Lb Al Required

(540) / (11.1 Lb/Gal) (4.37% Al)

= 1100 Gal Liquid Alum Required

... dose rate should be varied 3-5 times per day to meet P income at point of feeding; this is critical

... cam regulated feed control is attractive (33) (34)

... Figs 6-7: plot effluent P to see if peaks occur, adjust feed to correct; don't overcompensate

... Fig 8: keep varying coagulant feed until reaching desired P removal; stay on a given schedule at least 5 days (giving scant weight to the first).

b. Polymer: usually improves solids capture; may reduce metal salt demand enough to be economically attractive

... jar test several, then try in plant

... typical dose is less than one mg/l

... proper dose and dispersion: "slick fingers" test, turbidity

... feed rate is normally constant, perhaps reduced at night or interlocked with rate of wastewater flow.

c. Sampling and analysis: clear some space in the lab, Fig 9

... analyses for conventional treatment are continued

... coagulant analysis involves both anion and cation

... alkalinity is optional, unless effluent level drops to 50 mg/l

... turbidity of final is good test; lab unit or submerged disc

... observation of clarifier blanket is good control tool

... P analysis can be automated; daily composite also required, and is main test in stable operation

8. Sludge harvesting and disposal

a. Clarifiers: make it drop like a rock--and stay there

... be conservative in design: min 9-ft SWD for trickling filter plant, 12-ft for activated sludge, 500 gpd/SF based on average flow; 900 to 1000 gpd/SF on peak flow; good inlet system (try reaction jets or dissipating centerwells)

... preserve blanket, if possible, to serve as solids contact process; keep recirculation low in trickling filter plant

... floc is a good tracer, can indicate modifications

... modification can improve existing units (35).

b. Sludge treatment and disposal: the ever-present residue, but twice as much?

... expect good digestion, good gas production

... amt additional sludge depends on operation; percent solids should be higher than conventional; VS may increase 25% to 100% by weight but not necessarily volume; this is not all organic matter

... be courageous with digesters (often over-designed or under-operated anyway); provide heat and mix; consider thickening but treat overflow suspiciously; P will stay bound in sludge but supernatant will include colloidal P; consider operation toward high-rate range

... chemical cost for vacuum filter or centrifuge should be reduced in raw or digested sludge dewatering

... on drying beds: Fe sludge does better than Al which does better than conventional; drying time may be halved; don't draw beds too deep, and replace sand attrition for clear sweet underflow.

9. Supernatant, Rogue Pollution, and other happy thoughts

a. Simple supernatant system--that works

... fill-and-draw tanks; can be modified for continuous service

... Al/P dosage of 2/1, plus 20 minutes air, then settle

... draw sludge to beds or digesters; return clear water to head of plant

... lime may permit some NH_3 stripping.

b. Iron leakage: a new form of pollution, especially in trickling filter plants

... Fig 10: treating in final is worst

... polymer reduces escaping colloids

... Fig 11-12: iron is reduced thru plant, when added in primary.

c. Other radicals may be pollutants too; impact depends on local situation

... one pound Al (III) as alum adds 5.35 lb sulfate

... one pound Al (III) as aluminate adds 0.85 lb sodium

... one pound Fe (II) as chloride adds 1.26 lb chloride

... one pound Fe (III) as chloride adds 1.91 lb chloride

... one pound Fe (II) as sulfate adds 1.72 lb sulfate

... one pound Fe (III) as sulfate adds 2.58 lb sulfate.

10. Costs

a. Capital investment: a grassroots solution each time

... FRP tanks: $1/gal up to 1000 gal; 60¢/gal above 1000

... pipe, ftngs, vlvs: $1000/MGD (don't scrimp here)

... 3 HP mixer w/starter: $1000

... auto poly dispenser system: $4000

... chemical pumps w/starters and auto capability: $1500

... concrete, baffles, samplers, lab equip, auto controls, electric gear, shelter, etc.: estimate according to situation

... ratio of material/labor is high in these facilities

... capital costs are small part of total

b. Chemical costs: here's where the money is

... liquid alum (48.5% soln) at 24¢/lb Al; add freight (12¢/lb Al is typical for 250 miles); sodium aluminate costs near 35¢/lb Al, it includes alkalinity

... ferric chloride approx 12¢/lb Fe, plus freight (5¢/lb Fe typical for 250 miles)

... spent pickle liquor: anybody's guess

... cost = (P income) x (mole ratio for desired performance) x (unit cost)

... poly varies widely, 1¢/1000 gal is typical upper limit.

c. Other costs

... power is nominal, about $200/yr/MGD

... manpower: 24-hr intelligent operation (naturally this could be a major item in some cases); however, no additional operators are needed above those required for conventional plant

... lab support: if no analyst is planned, one should be; one can handle chemical treatment tests along with conventional analyses.

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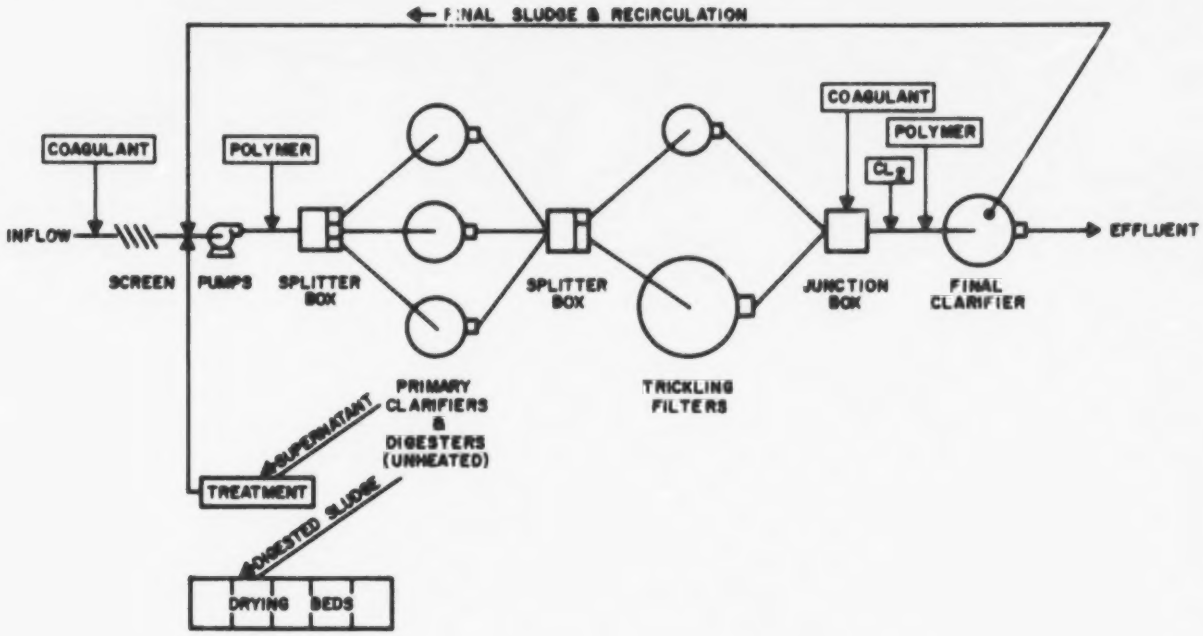
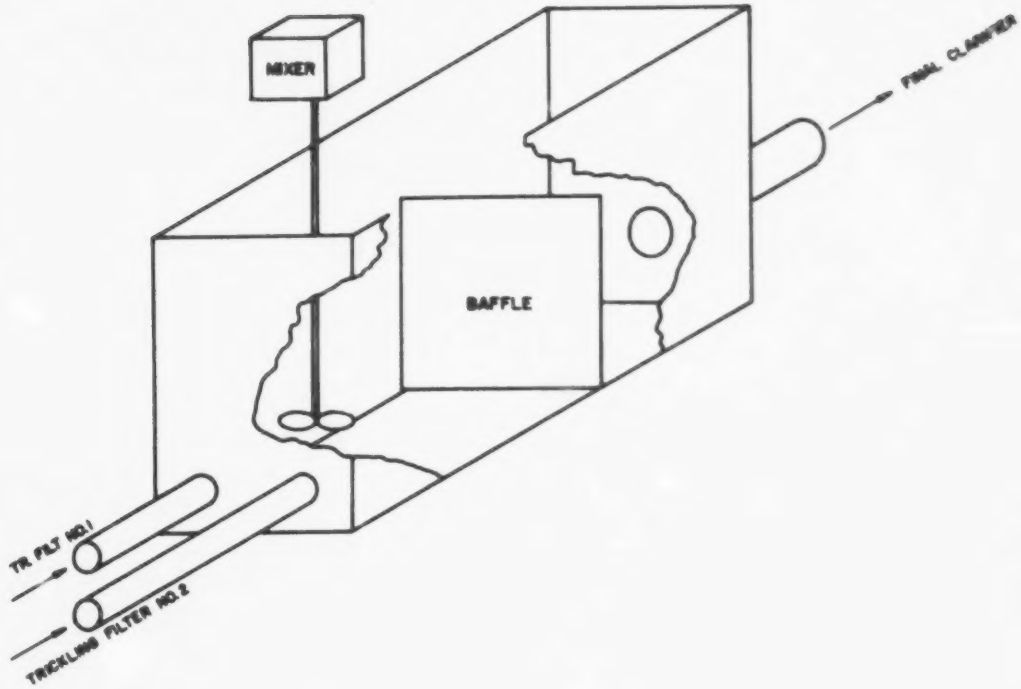


	Diam (Ft)	Depth (Ft)	Circum (Ft)	Area (Sq Ft)	Volume (Cu Ft)	Volume (Gal)
Primary Clarifier No. 1	40	8	126	1257	10,054	75,200
2	40	10	126	1257	12,570	94,000
3	40	10	126	1257	12,570	94,000
All Primary Clarifiers	--	--	378	3771	35,194	263,200
Final Clarifier	70	6	220	3848	23,088	173,000
Filter No. 1	84	6.5	---	5542(1)	36,000	---
2	120	6.5	---	11310(1)	73,500	---
Filters Combined	---	---	---	16852(1)	109,500	---
Digester No. 1	40	14.3(2)	---	1257	13,000	135,000
2	40	14.3(2)	---	1257	13,000	135,000
3	40	14.3(2)	---	1257	13,000	135,000
Digesters Combined	--	---	---	---	39,000	404,000

Sludge Drying Beds 12,000 Square Feet

(1) Area in acres: 0.127, 0.260 and 0.387, respectively
(2) 14.3 Effecitve, 18.0 SWD, 15.8 Clear @ Center

G I TREATMENT PLANT WITH CHEMICAL PRECIPITATION FACILITIES (REF 12)



Flow Rates		Coagulation	Flocculation Time (Minutes)		
MGD	GPM	(Minutes)	High Energy	Low Energy	Total
1	700	1.42	5.71	28.6	34.3
1.5	1,050	0.95	3.81	19.1	22.8
2	1,400	0.71	2.86	14.3	17.1
2.5	1,750	0.57	2.28	11.4	13.7
3	2,100	0.48	1.91	9.5	11.4

FIG 2 JUNCTION BOX MODIFIED TO FLASH MIX (REF 12)

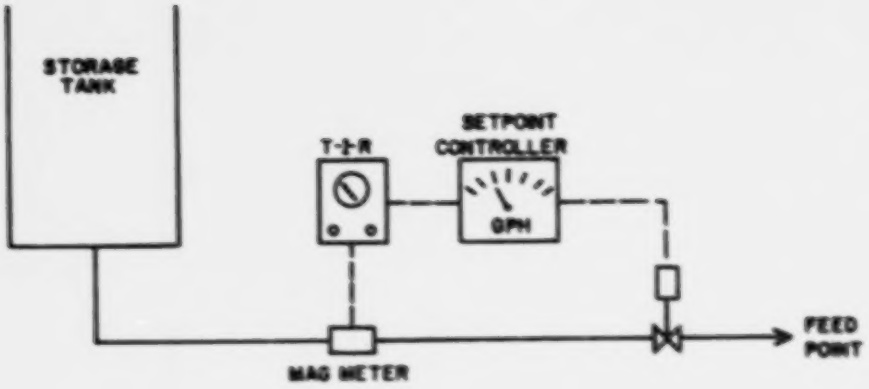


FIG 3 GRAVITY CHEMICAL FEED SYSTEM

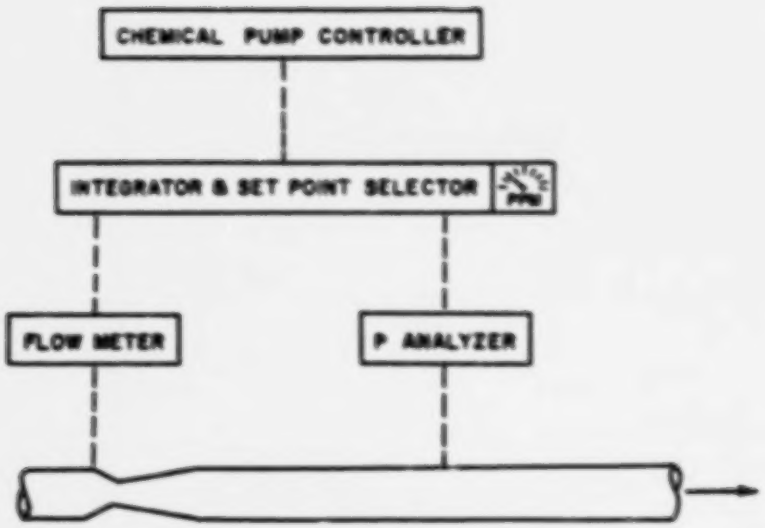
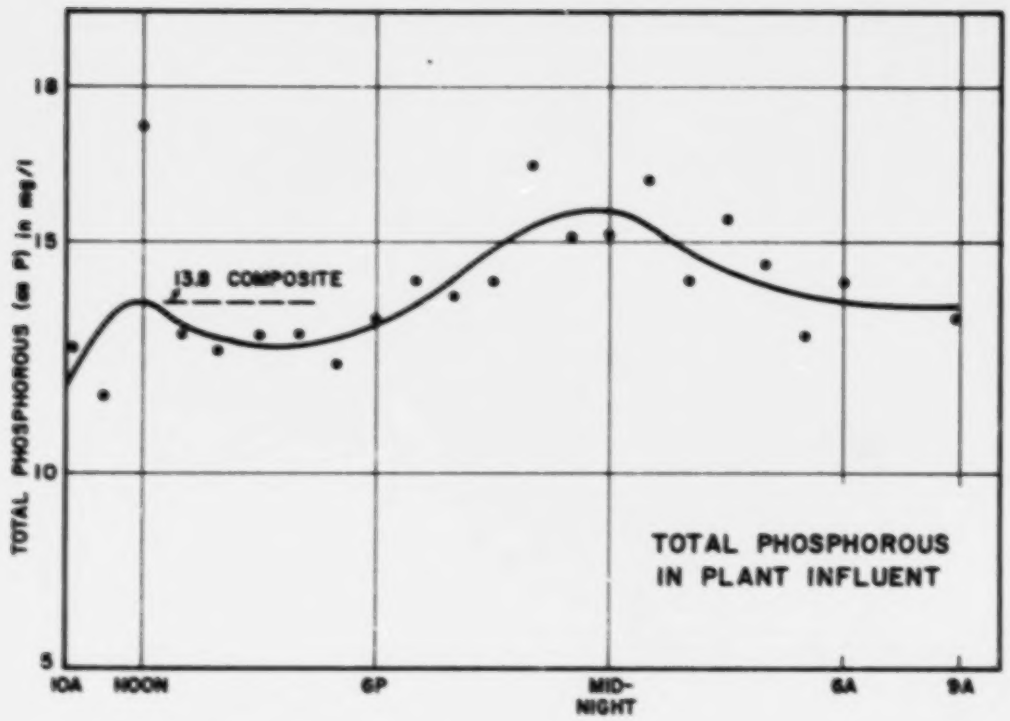


FIG 4 CHEMICAL FEED CONTROL BY COMPOUND LOOP



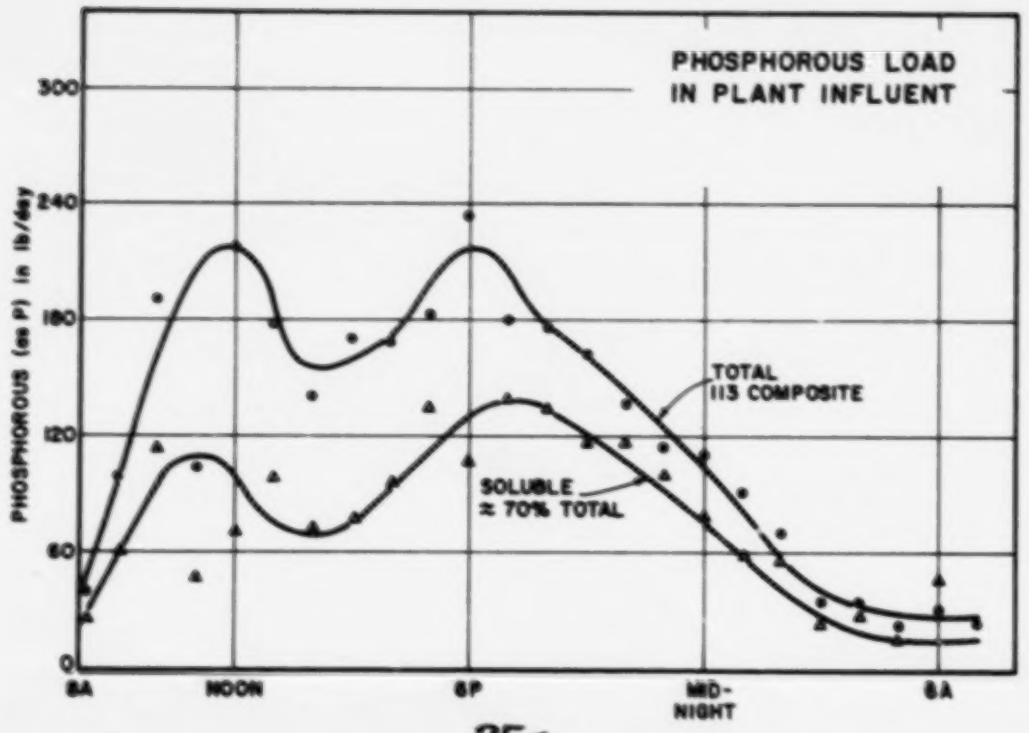


FIG 5 PHOSPHOROUS INCOME PLOTS (REF 12)

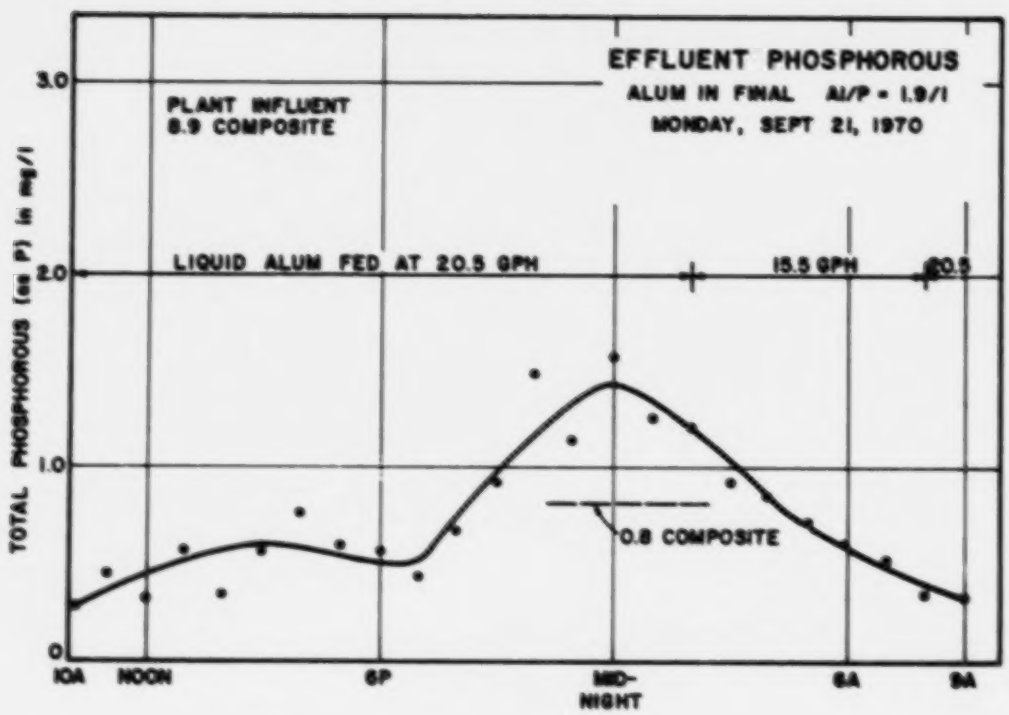
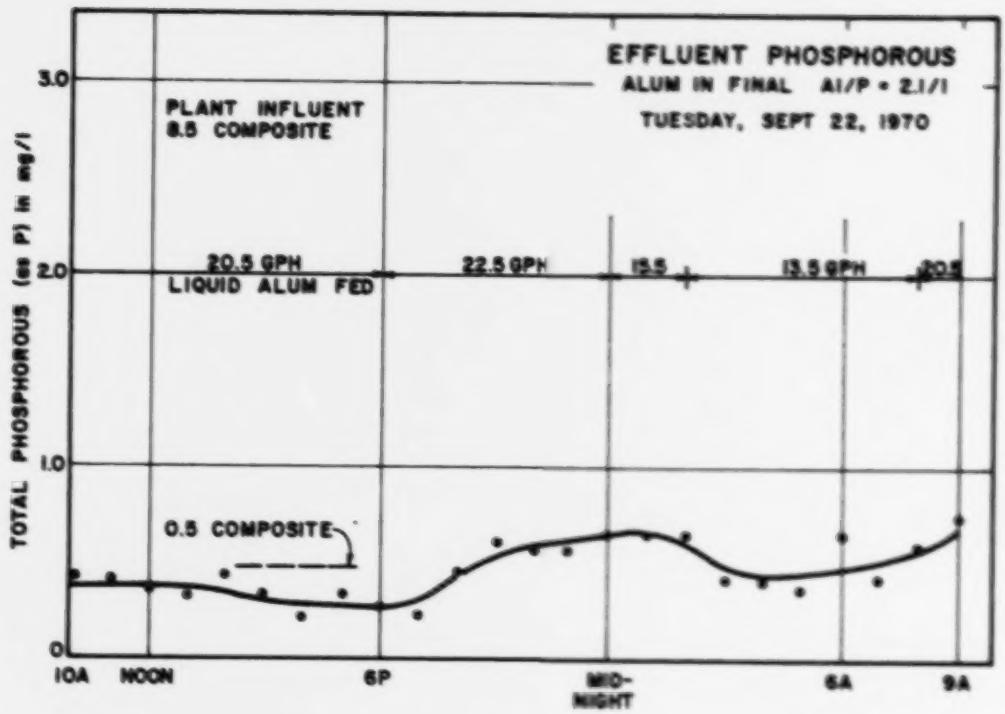


FIG 6 TOO FEW CHEMICAL PUMP SETTINGS GIVE POOR CONTROL (REF 12)



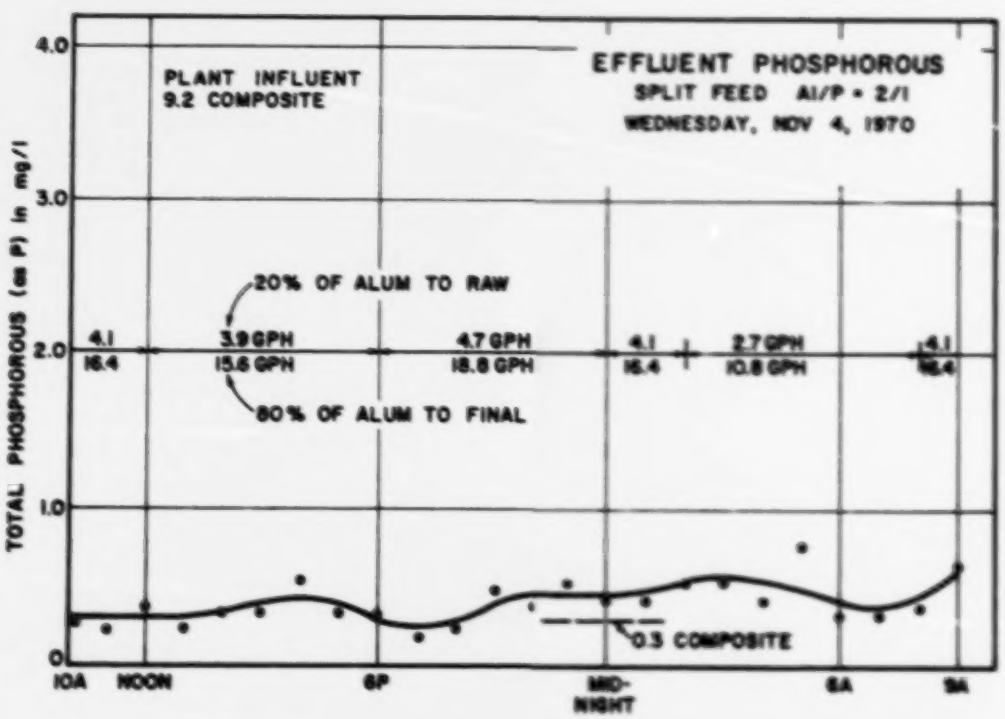


FIG 7 REFINED FEED ADJUSTMENT IMPROVES RESULTS (REF 12)

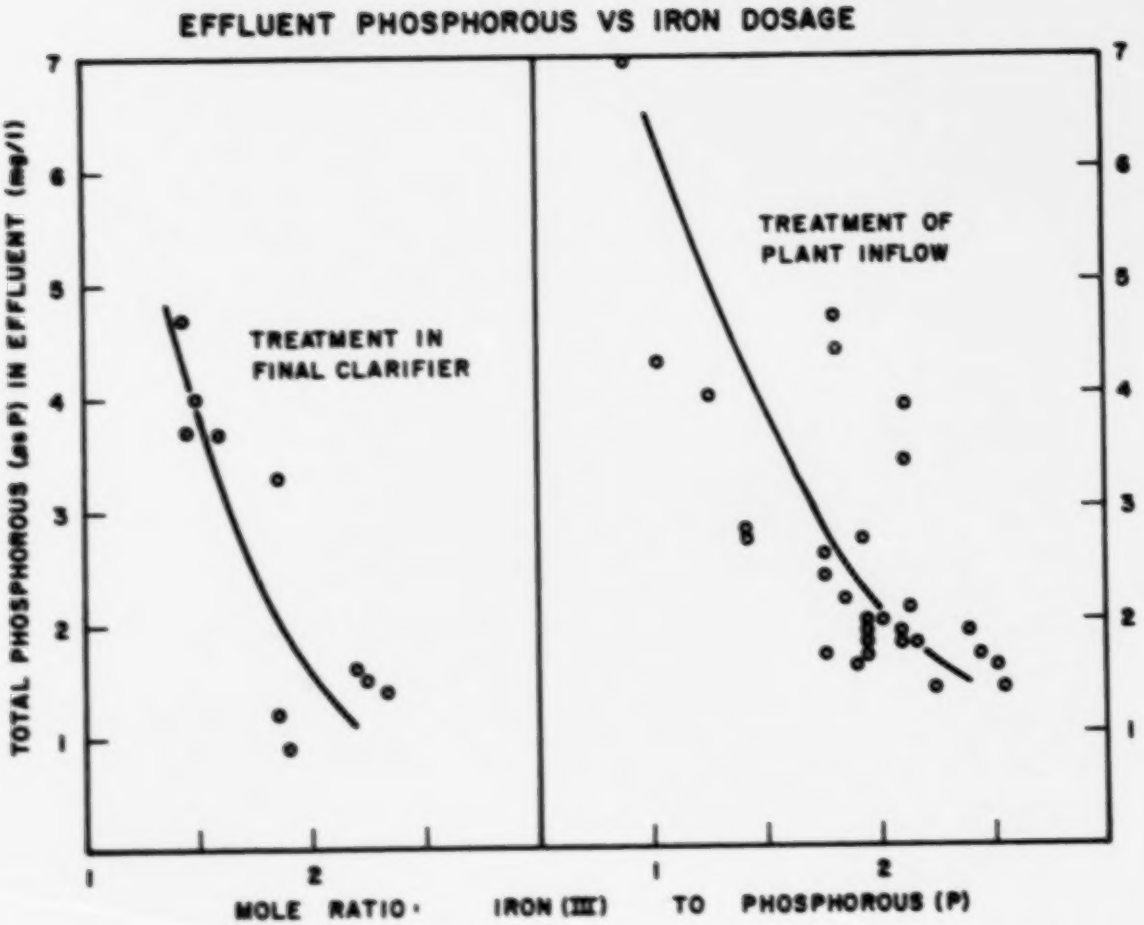

EFFLUENT PHOSPHOROUS VS IRON DOSAGE
TOTAL PHOSPHOROUS (as P) IN EFFLUENT (mg/l)
TREATMENT IN FINAL CLARIFIER
TREATMENT OF PLANT INFLOW
MOLE RATIO - IRON (III) TO PHOSPHOROUS (P)

FIG. 8 STUDY OF RESULTS ALLOWS SELECTION OF DESIRED MOLE RATIO

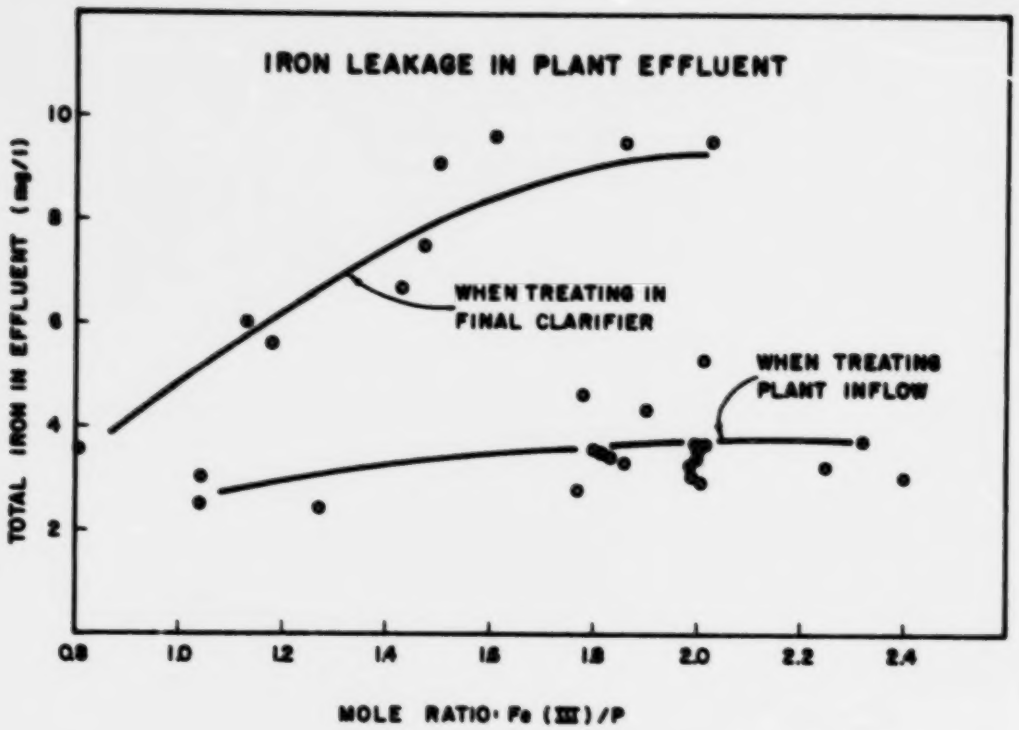
ANALYSES FOR CONVENTIONAL TREATMENT

	RAW	PRIM EFF	FILT EFF	FINAL EFF	RECIRC	SLUDGE	SUPERNAT
FLOW	●				●	●	●
TOT SOL	●	●	●	●	●	●	●
TOT VOL SOL	●	●	●	●	●	●	●
SUS SOL	●	●	●	●	●		●
SUS VOL SOL	●	●	●	●	●		●
SET SOL	●	●	●	●			
BOD	●	●		●			●
DO	●			●			
COD	●	●	●	●	●		●
PH	●	●	●	●		●	●
TEMP	●	●	●	●		●	●

ADDITIONAL ANALYSES FOR CHEMICAL TREATMENT

	RAW	PRIM EFF	FILT EFF	FINAL EFF	RECIRC	SLUDGE	SUPERNAT
PHOS	●	●		●	●	●	●
ALK	●	●		●		●	●
FE	●	●		●	●	●	●
AL	●	●		●	●	●	●
SO4	●	●	●	●		●	●
CL	●	●		●			
TURB	●	●		●			

FIG 9 CHEMICAL PRECIPITATION INVOLVES ADDED LABORATORY ANALYSES



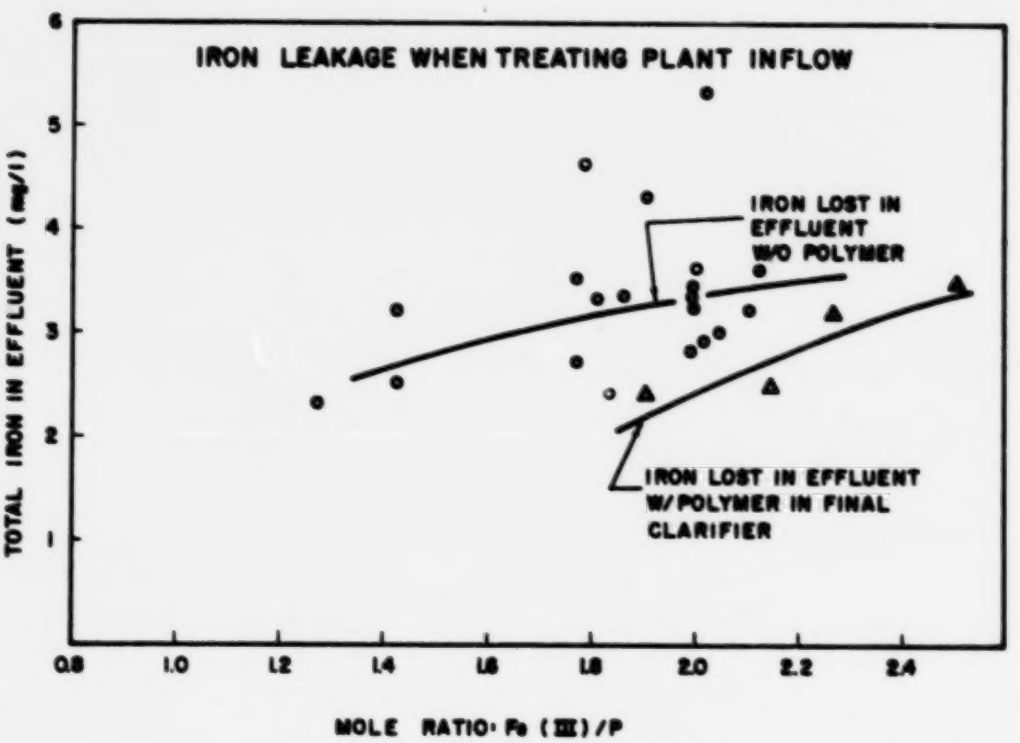
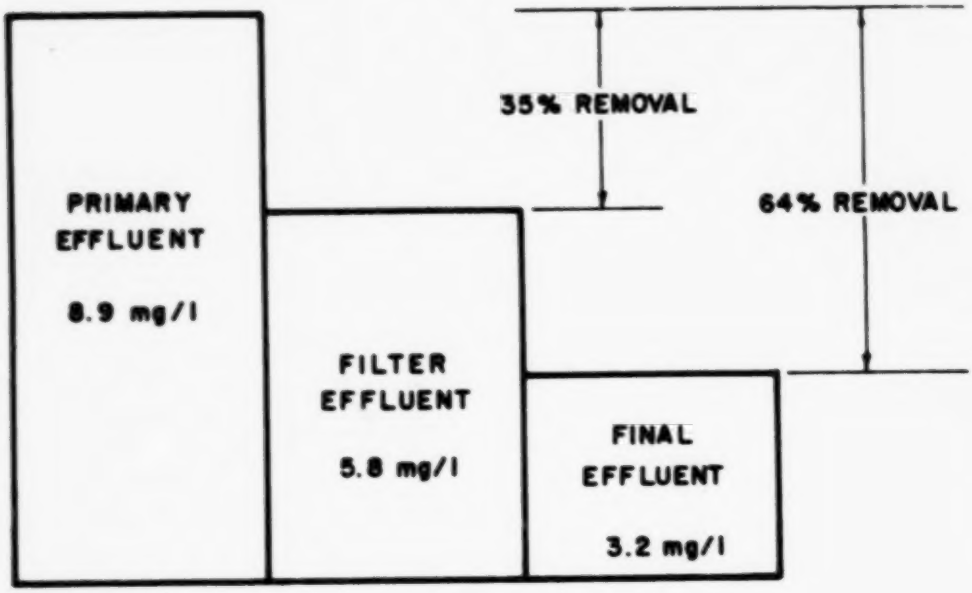
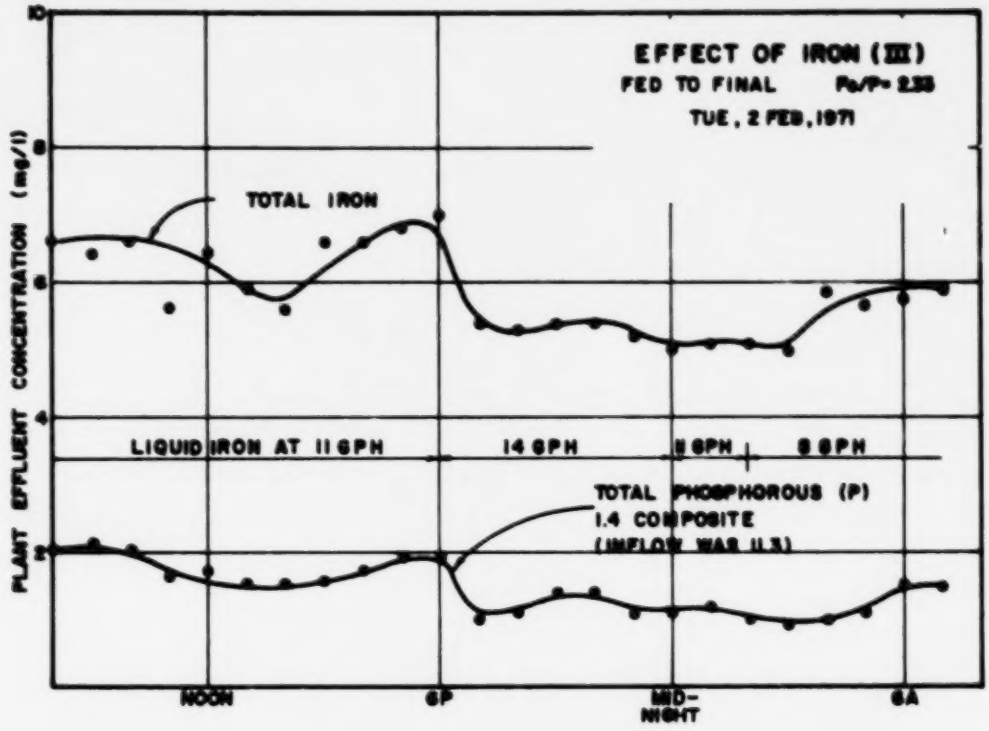


FIG 10 IRON LEAKAGE MAY BE A PROBLEM, POLYMER CAN HELP



IRON (III) LEVELS WITHIN PLANT
DURING TREATMENT IN PRIMARY CLARIFIERS
PLANT INFLOW = 0.85 mg/l Feb 10-Mar 9,1971

FIG 11 IRON REMOVAL WHEN FEEDING $FeCl_3$ TO PRIMARY (REF 12)



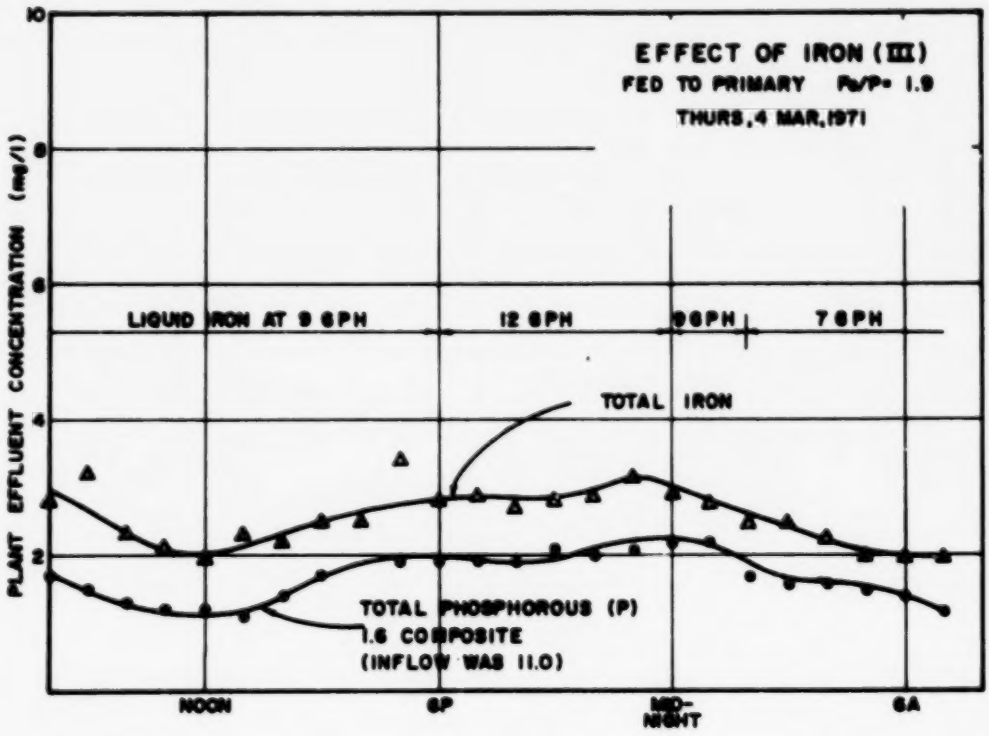


FIG 12 IRON MAY PERFORM BEST IN PRIMARY (REF 12)